Green Paper

Energy: A New Era

by Curtis Moore

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Just as the world made one energy transition from wood to coal in the 19th century and another from coal to oil in the 20th century, the evidence suggests that a third transition is under way as we approach the future. The world appears on the verge of a new era of advanced technologies and new fuels. Although such a transformation is unlikely to take place overnight, change is clearly coming. The question is how much and how fast: Will energy transition amount to a technological revolution, or merely an evolution?

Revolution or Evolution?

If it is revolution, the world will soon see new and utterly different ways of making and using energy. For example, electricity might be generated by zero-polluting wind or sunlight, then used to generate hydrogen that, in turn, would fuel zero-polluting factories, furnaces, and cars — perhaps even ships and airplanes. Rooftops would be shingled with panels that make electricity from sunlight, and farmers would harvest windmill-derived electricity together with their crops, bringing refrigeration and lighting to the furthest reaches of the world. Super-strong, lightweight, zero-polluting and recyclable cars would share the road with sleek-as-a-bullet trucks parallelling fast-as-a-bullet trains.

If evolution is the result, the world might continue to use pollution-producing fuels like coal, oil, and natural gas but in newer, cleaner, and more efficient ways. Both cars and power plants might double or even triple their efficiency, while slashing their pollution by 90 percent. Super-insulated homes and offices, super-efficient light bulbs and motors, and computer-controlled production lines might cut energy consumption — and, with it, pollution — by 75 percent. Instead of being built with furnaces and air conditioners, homes, offices, and even remote villages might be equipped with fuel cells — compact, quiet, super-clean devices that generate electricity chemically, yielding as by-products absolutely pure water, heat, and little or no air pollution. Cars and trucks would continue to run on oil-derived petrol and diesel, but they would be low-polluting "environmental" versions due to increasing competition from natural gas, methanol, and other cleaner fuels.

Tip of the Technological Iceberg

Whether the world will arrive at either of these scenarios or a mixture of the two will not be clear for several years. But propelled by a global population that is growing rapidly and standards of living increasing at an even sharper rate, change is clearly under way. Energy consumption is rising throughout the world, and, with it, levels of air pollution and congestion.

In response, laboratories and businesses are producing a sometimes bewildering array of technologically advanced ways of producing and using energy. There are smaller companies, of course, but much of the work is also being done by some of the largest corporations. Consider, for example, the following:

■ Virtually all of the world's major carmakers, ranging from General Motors to Toyota — as well as the Tokyo Electric Power Company, an investor-owned utility with roughly 25 million customers — have developed prototype electric cars and trucks. Hydrogen-fueled versions have been shown by BMW, Mercedes, and Mazda. Other versions developed by companies like Volvo and Toyota boast super-strong but lightweight bodies, low-rolling-resistance tires, high-efficiency engines, and other advanced equipment that enables them to travel 38 kilometers per liter on conventional petrol or diesel fuels.

■ The Swedish-German-Swiss conglomerate, Asea Brown Boveri (ABB), one of the world's largest power engineering firms, sells a power plant technology that burns coal but slashes pollution by up to 90 percent. Plants have already been built in Sweden, Spain, and the United States. One competing technology is offered by Lurgi, and two versions of yet a third are marketed by the rival oil companies Texaco and Shell.

■ For those who prefer natural gas, General Electric's (GE) "combined-cycle" systems — so named because they produce electricity by combining both steam and gas turbines into a single package — provide the basis for the world's cleanest, most efficient large power plants. At Tokyo Electric's 2,000-megawatt Futsu plant, for example, GE combined-cycle turbines work in tandem with a pollution control system known as selective catalytic reduction (SCR). Futsu generates electricity at 47 percent efficiency — about one-third better than the average power plant — with emissions that are one-tenth those of other systems. An even cleaner and more efficient plant is under construction. Not to be outdone, GE's rivals, Siemens and Asea Brown Boveri, have developed their own combined-cycle systems.

■ Zero-polluting wind turbines that generate electricity for the same or less cost than coal can be bought from several U.S. companies, while solar cells are being sold by more than a dozen companies.

■ Fuel cells, which chemically convert hydrogen or a hydrogen "carrier" like natural gas or methanol into electricity, are being installed in pre-commercial units in Japan, the United States (California), and other areas of the world. The parent companies of the enterprise include International Fuel Cell Corporation, a subsidiary of United Technologies. Other fuel cells are marketed by Fuji Electric, a Japanese conglomerate, and Ballard Industries of Vancouver, Canada.

These products are merely the tip of a technological iceberg. Literally hundreds of other innovations are entering the global markets, most finding customers who are anxious to buy products that are not only cleaner but very often better, faster, and cheaper as well. But to understand why there is such a burgeoning array requires a brief review of where the world stands with respect to energy and the recent past.

New Threats to Energy's Future

The environmental threat that has captured the world's attention and precipitated the current technological flood is global warming — an increase in the earth's temperature due to air pollution, especially carbon dioxide. Although most scientists agree that the unequivocal detection of the enhanced greenhouse effect is not likely for a decade or more, they also have issued uncharacteristically dire warnings that waiting until warming is actually measured runs the risks of profound, irrevocable change. To stem that change, the world needs to concentrate on three areas:

Population increases. For centuries, the one constant in an otherwise changing world has been a steadily expanding population. Since 1950, it has doubled, rising from 2.5 thousand-million persons to roughly 5.2 thousand-million. Most of this growth has occurred in developing nations: In 1990, for example, 77 percent — or, 4.1 thousand-million — of the world's population lived in developing nations. The proportion living in the developing versus the industrialized nations is likely to increase further because the population growth in industrialized nations has become relatively modest. The populations of Germany and some other countries, for example, are growing not at all, while the birth rates of less developed nations are three to five times as high. It is projected that within another 30 years, the population of the industrialized nations will have grown by about 150 million, while that of the developing world will have shot up roughly 3 thousand-million.

Importantly, there are now far more young people in the developing nations. As they approach adulthood — that is, child-bearing age — population will shoot up further and, with it, energy consumption as they establish separate households, buy vehicles, and use energy-consuming appliances such as refrigerators.

Increased consumption. As the global population has increased, so has the standard of living and, with it, the demand for goods that consume energy — and produce pollution. In industrialized nations such as the United States, much growth in energy use has been attributed to larger or greedier goods — refrigerators with two doors and larger capacity, for example, or cars with bigger engines. In developing nations, energy growth has been attributed to the spread of technologies and products that industrialized nations have long taken for granted: cars, refrigerators, water heaters, and air conditioners.

Thus, the things that consume energy and directly or indirectly cause pollution have increased vastly faster than the population. In 1950, for example, there were about 70 million vehicles on the roads. Today, that number stands at about 550 million, an eightfold increase. During that same period, population only doubled, which means that motor vehicles are increasing four times as fast as humans. As a result, except for brief interruptions during the oil crises between 1973 and 1975, and again between 1979 and 1982, global energy production has risen steadily over the last 20 years and is now about 50 percent above 1970 levels. Coal, oil, and gas account for over 90 percent of production. Still, most energy is consumed by the industrialized nations, which use about 10 times as much per person as the developing countries.

One reason for this disparity is the increasing demand in industrialized nations for bigger and better housing. In Europe, North America, and Japan, the number of houses has increased since 1972 at rates ranging between 1.1 and 1.9 percent per year. The houses are larger, too: The increase in living area per person ranged between 1.4 and 2.1 percent per year between 1972 and 1987. And they are better equipped: The number of homes with central heating systems rose sharply as well, jumping from about 40 percent in 1972 to 70 percent in 1987 in Germany, France, Italy, and Britain. Refrigerators and freezers increased in size, while new appliances made an appearance. In France, for example, although clothes dryers were, in the words of one expert, “virtually unknown” before 1985, they are now selling at the brisk clip of 500,000 units per year.

Still, because most industrialized nations embarked on aggressive energy conservation campaigns after the oil crises in the 1970s and 1980s, much of the 50 percent growth in energy consumption during the last two decades has been in developing nations. There, total consumption of commercial energy has almost tripled since 1970 and is expected to triple again by the year 2025. Most of this has been in the use of coal and oil. Despite this rapid and sharp rise in energy use by the cities of developing nations, most rural populations still rely on firewood, animal and plant waste, and charcoal for cooking, heating, and lighting. For other tasks — irrigation and farming, for example — most of the world’s 2.5 thousand-million rural villagers must rely on farm animals and their own brawn.

Rising pollution. As rampant population growth and industrialization have struck one developing nation after another, large cities have become cauldrons of pollution. For example, the death rate jumps 500 percent on the most polluted days in metropolitan Athens. In Mexico City, considered by many to have the world’s dirtiest air, ozone or “smog” levels routinely triple the limits recommended by the World Health Organization. The city’s 36,000 factories account for some of this pollution, but roughly 80 percent of it is spewed from the tailpipes of the 3 million cars and trucks that gulp 19 million liters a day of low-quality and leaded gasoline.

The World Health Organization estimates that 70 percent of the global urban population breathes air that is unhealthy at least some of the time, while another 10 percent breathes air that is “marginal.” Studies of sulfur dioxide and sulfate particulates — which arise from the combustion of sulfur-containing fossil fuels such as coal — have linked these pollutants to bronchial diseases and wintertime illnesses in children.

Between 1979 and 1985, eight of 10 monitoring stations in China reported increases in sulfur pollution. At some of these sites, concentrations were three to five times those found anywhere in North America. Similar, though less severe, conditions prevail in New Delhi, Jakarta, Tehran, Manila, and Bangkok, among others.

Pollution levels are dangerously high in some industrialized nations, also. In Krakow, Poland, for example, damage to stone monuments and buildings is so severe that the stone is described as “melting.” In parts of the former Czechoslovakia, whole forests have died. And ozone and acid rain have been implicated in forest decline throughout other areas of Europe and North America.

Even in areas remote from industrial facilities, air pollution can be damaging. In the rain forests of Africa, for instance, scientists report acid rain and smog levels as high as those of central Europe, probably from the regular burning of the vast grasslands to clear land.

Responses to the New Threats

With concerns over the new threats escalating and the continuing reliance on Middle East oil reserves, policy-makers around the world already have begun searching for solutions.

Conservation. By increasing the efficiency with which energy is used, total societal consumption can be decreased, thus reducing emissions. Energy use in most industrialized nations was profoundly altered by the oil crises of the 1970s. Most developed nations rapidly deployed strategies aimed at reducing oil consumption, increasing efficiency, and developing non-petroleum energy sources. As a result, energy consumption and economic growth were, for the first time in memory, decoupled. National economies, such as Japan's, grew, while their energy consumption shrank. The amount of energy required to produce a unit of gross national product dropped by 25 percent in the member nations of the Organization for Economic Cooperation and Development. Some reductions were even greater: Japan, Denmark, and Britain reduced their energy intensity by 30 percent.

These policies largely had their desired effect: Oil imports grew slowly through the 1970s, then began to decline in the 1980s. Japan, where net imports of oil grew by 15 percent, and the United States, where they more than doubled, were exceptions to this trend. Conservation alone, however, did not account for declining oil imports. Coal production increased — at least initially — but perhaps not as much as would have been expected.

Cleaner fuels. By burning cleaner, less-polluting fuels, emissions can be sharply reduced. Despite the depletion of oil reserves and the global abundance of coal, its consumption since 1970 has increased by only 22 percent — less than half the rate of overall energy use. Similarly, consumption of the second-most polluting of fossil fuels, oil, has dropped slightly, despite declines in real prices that began in the mid-1980s. By contrast, consumption of natural gas, the cleanest of the fossil fuels, has grown steadily and now nearly equals coal. Most increases in coal consumption were attributed to its use in the production of an even cleaner end-use energy, electricity. Because of electricity's flexibility and lack of pollution at the point of use, electricity consumption has jumped almost 50 percent since 1973. Much of this was generated by coal, though electricity produced from nonfossil fuels, especially nuclear, was also up sharply.

Most governments have also encouraged switching to renewable energy sources such as geothermal, solar, biomass, and wind power. As a result, these nonpolluting and often inexhaustible sources provide up to 5 percent of the total energy requirements in nations such as Australia, Austria, Canada, Denmark, Sweden, and Switzerland.

New technologies. Adopting new technologies that are either inherently less polluting or highly efficient — and thus less polluting — can, for example, reduce emissions from power plants. It is in the development of new technologies, however, where oil and environmental adversities of the past have had their most profound and lasting impacts.

The technologies available for reducing energy consumption and air pollution include both "supply-side" controls — those at the point where the energy is generated — and "demand-side" — those at the point where energy is actually consumed.

Supply-side technologies fall into several categories: energy combustion or conversion technologies used in power plants for converting fossil fuel energy into electricity; supplementary pollution control technologies such as catalytic converters for reducing oxides of nitrogen, carbon monoxide, and hydrocarbons from motor vehicle exhausts; and energy conservation practices such as co-generation, in which the heat that would otherwise be merely vented into the air is put to some use, such as heating or cooling a building or running a paper mill.

Technologies on the demand side include those that reduce energy consumption while still providing the same level of output. New light bulbs and associated equipment, for example, provide the same or better illumination with such great efficiency that they save money over their 10-year lifetimes. Comparable savings can be realized with new motors and drive controls, "Low E" windows that eliminate the heat-producing rays of the sun, and a variety of other devices.

New Technologies Using Old Fuels

Coal. Historically, coal has been converted to electricity by grinding it, then burning it in what are known as "pulverized coal" power plants. Using older technology, with no add-on controls, coal then produces devastating pollutants, causing acid rain, smog, and global warming, while polluting rivers, lakes, and oceans with toxic metals.

But this need not happen. Using either well-established technologies or newer and more efficient ones, it is

The Big Three: Coal, Natural Gas, and Oil

Coal. *The cheapest, most abundant, and dirtiest of the three most important fossil fuels, coal is rich in carbon and produces prodigious amounts of pollution when burned. Although coal is not only the dirtiest of the fuels but one whose production can ravage the landscape, the pressure to continue using it is immense.*

Coal is easily the most widely distributed of the three major fossil fuels, and it has a reserves-to-production ratio of 390 years. Over 60 percent of the world's coal reserves are found in developing countries, 50 percent in China alone. Among industrialized countries, the former Soviet Union and the United States have the largest reserves, with 13 percent and 12 percent, respectively.

Despite growing concerns over global warming, acid rain, and other effects, coal continues to be widely used. Central Europe and the former Soviet Union still rely heavily on coal, although it contributes to urban pollution so severely that buildings and monuments are sometimes said to be "melting" from its corrosive effects.

Coal is the most important source of energy in Poland and the former Czechoslovakia, and it powers the industrial sector of Bulgaria. The majority of households in those nations and also in Hungary burn coal to heat their homes: 47 percent of all coal consumed in Poland and 75 percent in Hungary goes to the residential sector.

In the East, China's economy depends on coal for 73 percent of its energy needs, with one-quarter of all coal being burned for residential heating, thus contributing to severe urban air pollution. China, India, South Africa, and the Democratic People's Republic of Korea produce 92 percent of the coal from developing countries. In other developing countries, coal reserves are large but poorly estimated because exploration activities have been less extensive.

Natural Gas. *Developing and industrialized countries each share half of the world's natural gas reserves. The lower output level in the developing countries puts the reserves-to-production ratio at 155 years, compared to 39 years in industrialized nations. The former Soviet Union has the world's largest natural gas reserve, with 38 percent of the total.*

Natural gas has emerged as the most important energy source in the non-OECD (Organization for Economic Cooperation and Development) industrialized countries, surpassing oil in 1983 and coal in 1987. This shift was primarily due to the former Soviet Union's supply-oriented energy policy, which shifted financial resources into the oil sector when coal production stagnated in the late 1970s, and then into the gas sector when oil production leveled off in the 1980s.

Oil. *While still substantial, reserves of oil are smaller than those of either coal or natural gas. The world's oil reserves are estimated to be 124 thousand-million metric tons, or 40 years at 1989 production levels. Developing countries account for over 86 percent of world reserves, with the majority found in oil-exporting countries. Proven reserves in industrialized countries are almost evenly divided between OECD and non-OECD, each group having a reserves-to-production ratio of a little over 10 years.*

In many industrialized nations, the oil shocks of the 1970s remain vivid memories, sustaining efforts to develop alternatives to petroleum. As a result, since 1973, oil consumption in most industrialized nations has generally declined for generating electricity, heating, and industrial uses. In most nations, petroleum use for transportation has also declined, although in the United States it has actually increased, leaving the nation more dependent on imported oil today than it was 20 years ago.

Despite these declines, oil remains the world's largest single energy source, accounting for about 39 percent of global supply in 1989, followed by coal (28 percent), natural gas (21 percent), hydropower (7 percent), and nuclear power (6 percent). Given the massive capital investment in pipelines, storage tanks, engines, and thousands of millions of dollars worth of other goods designed to run on oil, this dominance is unlikely to diminish soon or rapidly.

possible either to burn coal more efficiently or gasify it. In a system relying on gasification, either combined-cycle systems or "aircraft-derivative" turbines — based on the jet engines that push airplanes through the air at nearly the speed of sound — can be incorporated to boost efficiency and reduce pollution.

One such system is the "integrated gasification-combined cycle" (IGCC), which turns coal into gases using two turbines. First, coal gases are burned in a gas turbine that has been in widespread use since the early 1960s. Then, excess heat — which is typically vented to the atmosphere in most power plants — is instead used to drive a steam turbine.

Often, IGCC is referred to as "Cool Water" technology, a name drawn from the ranch in California's Mojave Desert that once occupied the site where it was developed. Coal of all sorts burns so well with the Cool Water technology — up to 99 percent of sulfur contamination is eliminated, for example — that the U.S. Department of Energy projected that this technology could potentially halve U.S. emissions of sulfur dioxide, the principal cause of acid rain, while holding electricity costs level, or, in many cases, lower than conventional options.

Cool Water is by no means the only technology for cleaning up coal. When a finely pulverized mixture of coal and other materials is suspended in midair by a stream of upward flowing air, it behaves much like a fluid. Powdering coal and burning it in systems using such "fluidized beds" provides more complete combustion, thus increasing the amount of energy squeezed out of it and lowering the pollution. While there are several types of fluidized-bed systems, they share an ability to burn a range of fuels with greater efficiency and less pollution than old-fashioned pulverized coal boilers. Indeed, one system in Duisberg, Germany — a "circulating bed" — produces so little pollution that it is surrounded by apartment buildings located just off the center of the city. Another system — this one a "pressurized bed" — is five minutes from downtown Stockholm, also surrounded by apartments.

At the heart of all these systems is a turbine — an engine whose rotary fins are turned either by pressure from steam or from the rapid expansion of hot gases. Turbines whose blades are turned by combustion gases are called "gas turbines," and those that use steam are, naturally enough, "steam turbines." Rapid advances in both these types of turbines have made it possible to sharply boost the efficiency with which they generate electricity. The most pronounced progress has been made with gas turbines, which can run on fuels ranging from powdered coal to carbon monoxide but usually are fueled with natural gas.

Natural gas. The most intrinsically clean of the fossil fuels, natural gas also facilitates adoption of a range of technologies that are more efficient and cleaner burning than their coal- and oil-fired counterparts. Thus, converting to natural gas can, in effect, reduce pollution in two stages: first through conversion to a lower-polluting fuel; and, second, through adoption of more efficient, less polluting technologies.

Many of these technologies, such as combined-cycle turbines, are well established, reliable, and commercially available from major manufacturers. Other technologies — car and truck engines optimized to burn natural gas, for example — are fundamentally the same as conventional versions and would require little retooling.

Natural gas or petroleum oils may be used to fire turbines directly. In "simple-cycle" turbines, the hot combustion gases spin the turbine shaft to generate electricity. Aircraft-derivative turbines are simply jet engines that are used to generate electricity rather than propel an aircraft or other vessel. The advantage of aircraft-derivative turbines is that they are compact, easy to repair and replace, highly reliable, and flexible. If injected with steam, the efficiency of these turbines increases, and emissions of oxides of nitrogen, which cause both smog and acid rain, decline. If these turbines are equipped with an "intercooler," efficiency climbs further to 55 percent and emissions decline even more.

When gas-fired and steam electric turbines are coupled — as in the Cool Water technology — it is called a "combined cycle." Combined-cycle systems now in operation at the Tokyo Electric Power Company plant in Futsu, Japan, achieve an efficiency level of 47 percent. An efficiency of 52 percent is considered likely in newer combined-cycle systems. Siemens offers systems that it's willing to guarantee in writing will achieve comparable levels of efficiency.

Yet the most promising near-term use of natural gas may be as a "carrier" for hydrogen in a little known device called a fuel cell. A laboratory curiosity until the space race, fuel cells were developed to provide power for the U.S. space shuttle and other such craft. When fueled with hydrogen, they convert it chemically into pure, drinkable water and electricity. There's zero pollution and zero noise. Fuel cells can also run on fuels that are rich in hydrogen — natural gas or methanol, for example. Although they produce some air pollution, it is vastly less than conventional engines. The emissions of oxides of nitrogen, for example, are often so low that they cannot be measured with today's commercial instruments. In terms of overall efficiency, the worst fuel cells are better than the best conventional engines. A typical automobile engine, for example, operates at about 18 percent efficiency — wasting the rest of its gasoline as heat — while a comparable fuel cell runs at twice that, and efficiency levels of 75 percent are achievable.

Because they are compact, quiet, and either low or zero polluting, fuel cells also can be located in city centers and even inside occupied buildings, eliminating the need for transmission lines, right-of-way corridors, and the corresponding energy losses. Equally important, the heat from a fuel cell can then be used to warm or cool air or to operate laundries, or it can be put to some other use to boost total efficiency to 90 percent. Fuel cells are already in pre-commercial operation at a small number of locations throughout the world, and assembly lines have recently started production in Japan and the United States.

Oil. The oil crises of the 1970s and 1980s created an uneasiness in those nations dependent upon oil, increasing interest in vehicles and factories that run on non-petroleum fuels. Despite these efforts, petrol- and diesel-fueled motor vehicles collectively create more urban pollution than any other single human activity. They account for more than half of many urban air pollutants, and nearly half of others in industrialized and developing nations alike. Motor vehicles also generate prodigious amounts of carbon dioxide, the leading cause of global warming. Motor vehicles in the United States, for example, generate one of every 20 kilos of carbon dioxide in the world — more than all of Japan.

Although seemingly reluctant to do so, oil refiners can respond to some of these environmental concerns and have done so, in some cases, by developing "reformulated" fuels that produce less pollution; emissions of benzene, which causes leukemia, are slashed by up to 90 percent in some blends, for example. Moreover, there is no technological reason that many new energy systems — aircraft-derivative turbines or fuel cells, for example — cannot be run with petroleum-based fuels. Even conventional engines can be made cleaner burning with improved clean-up technologies such as electrically heated catalytic converters that "light off," or start, faster because they are pre-heated with electricity. Still, refiners are proving slow to change, and some governments and industries are intent on looking ahead a generation, past the point where global oil reserves should begin to decline.

For this reason, if none other, interest in non-petroleum fuels is clearly growing. BMW, Mercedes, and Mazda have all developed hydrogen-fueled cars. Ford offered a "flex-fuel" system in its 1993 models that burns either gasoline or methanol, and Mercedes is planning to do the same.

Other innovations are in the works. Leading the field is the catalytic converter, developed in California some 25 years ago. Today's models eliminate 90 percent of the hydrocarbons and carbon monoxide, and 60 percent of the oxides of nitrogen. Other innovations include vehicles that are run on electricity, fuel cells, natural gas, and battery power.

General Motor's "Impact" is the most efficient of the battery-powered cars produced to date. It consumes about 0.12 kilowatt-hours per mile. A U.S. auto fleet composed of Impact-like cars travelling 1.5 million-million miles per year — the current number of miles travelled in the United States — would increase electricity demand by only 7 percent. By the year 2010 or thereabouts, battery-powered cars should have a firm grip on the market, assuming reasonable progress has been made in reducing weight and recharging time while extending range.

Zero-Polluting Energy Technologies

What exactly will the dominant fuels of the future be? Will they be zero-polluting fuels or cleaner-burning coal, oil, and natural gas? Or will the dominant fuels comprise other sources that have not reached their potential? Many people believe that zero-polluting energy is an inevitability; that is, wind, solar, hydropower, or even nuclear power will be the status quo.

Wind power. Wind turbines — devices for converting wind into useful mechanical or electrical energy — are among the oldest sources of nonpolluting energy. Yet they were not widely used in the modern era until the 1970s and 1980s, when the United States adopted a variety of programs to encourage their use. In California, where utility and other regulations were adopted to encourage the development of alternative energy sources, 8,469 turbines were operating by the end of 1984. The total capacity of these units was approximately 550 megawatts electric (MWe). Almost all were erected at windy locations, in clusters called "wind farms." By the end of 1984, many thousands of wind machines, with a total installed capacity of over 650 MWe, were producing electric power in the United States.

Still, wind turbines were plagued by nagging problems: Wide swings in wind speeds would create roller-coaster surges and dips in electricity, sometimes damaging transmissions. Blades would collect debris, which hindered performance.

Manufacturers doggedly tackled these problems, however, and with recent improvements, wind turbines deployed in large arrays are now modern, state-of-the-art machines that can generate prodigious amounts of electricity — enough to power the city of San Francisco, for example — at prices that compete with fossil-fired power plants.

With improvements in such areas as blade design, wind turbine efficiency is boosted by 25 percent, while new gear mechanisms and generators allow the machines to squeeze more electricity from gales and breezes alike. New turbines can generate electricity for about 5 cents per kilowatt-hour — less than the price of coal-fired power.

As the technology has improved, its use has expanded also. Roughly 80 percent of the world's wind energy is generated in California, but wind power is expanding into the American Midwest, Europe — especially Belgium — and other areas.

Given the short time within which a wind farm can be deployed and operating — from one to two years, excluding wind data gathering — growth under favorable circumstances could be extremely rapid. It is possible that the market potential for wind turbines could be as high as 21,000 MWe for the period between 1990 and 2000.

Solar power. Solar power has not enjoyed the recent success of wind, but it is rapidly filling niches and, if prices continue to drop, could soon compete with large central power stations. Indeed, solar "thermal" systems, in which the sun's rays are used to superheat a fluid that is then used to drive an electricity-generating turbine, already produce power at close to competitive prices.

The most elegant form of solar power, however, remains the "photovoltaic" system, in which the sun's light energy is converted directly into electricity. It is the ultimate form

New Zealand's Compressed Natural Gas (CNG) Vehicle Program

When the oil crisis of 1978 hit, the government of New Zealand established the Liquid Fuels Trust Board, aimed at "the reduction in the importation of petroleum." Funded at between U.S. $2 and $3 million through a 0.1 percent tax on gasoline sales, the board evaluated over 400 possible options but heavily supported efforts to convert the nation's vehicle fleet to natural gas.

Most of the established infrastructure for storage and handling of compressed natural gas had been developed in Italy and the United States. New Zealand systematically adopted, modified, and improved these technologies, producing:

- *A quick-connect "trickle down" storage and refueling system capable of such rapid refills that a heavy-duty transit bus can be refilled in under four minutes — less time than its diesel counterpart;*
- *Lightweight yet strong on-board storage tanks capable of withstanding virtually every conceivable accident; and*
- *A variety of conversion specifications, standards, and parts suitable for a vehicle fleet that must be one of the world's most diverse.*

To encourage station owners to offer CNG and car owners to convert their vehicles, the government and the natural gas industry offered a variety of incentives. These included:

- *A conversion bounty of NZ$150 (later raised to NZ$200) for car owners;*
- *Low-interest, no-down-payment loans for the balance of the conversion costs;*
- *Subsidies for the natural gas companies covering up to 40 percent of the cost of extending pipelines to service stations;*
- *Gas company coupons providing NZ$2 per fill-up to motorists;*
- *A highway natural gas tax that was considerably less than that for gasoline; and*
- *A pricing disparity between natural gas and gasoline that left CNG with a 33 percent price advantage.*

What this government-inspired program yielded was the highest per capita use of CNG vehicles in the world — or, put another way, the world's most successful alternative fuel program. By 1988, roughly 11 percent of the nation's vehicles — about 120,000 in all — had been converted to run on compressed natural gas. Within one decade, New Zealand converted one-tenth of its vehicle fleet to natural gas and established a fueling infrastructure. This represents the highest rate of penetration by CNG in any country's motor vehicle fleet, and it is certainly an astounding accomplishment for a program that is barely a decade old.

of energy: free, plentiful, and utterly nonpolluting. Photovoltaic systems, which can be bought off the shelf and erected in a matter of hours, will power everything from isolated villages to inner-city townhouses. Panels can be bolted to the ground or a roof, or even molded into shapely curves. The devices seldom fail, and even when one does, the rest keep on working, in bright sun or skies dimmed by clouds.

Unfortunately, solar photovoltaic electricity still costs two to five times that of coal, oil, or natural gas. Moreover, the systems do not work at night. Still, some countries are pressing ahead with plans to deploy what could be the ultimate source of electricity. Japan and Germany, for example, have subsidized residential purchases of solar panels. Switzerland and Austria have both mounted aggressive development programs, and interest has been rekindled in the United States.

Hydropower. In announcing his plans for a national program to return U.S. emissions of carbon dioxide to 1990 levels by the year 2000, President Bill Clinton will rely heavily on deployment of new technologies and alternative energy, especially hydropower. Of all the renewable energies, this has been most widely deployed, though recent development of large-scale hydropower projects in developing countries has been slowed by financial problems and social and environmental concerns. Still, only a small proportion of the potential hydropower in developing countries has been harnessed: 5 percent in Africa, 8 percent in Latin America, and 9 percent in Asia. China has tapped about 10 percent of its 378-gigawatt exploitable potential, the world's largest. A greater share of hydropower potential has been developed in industrialized countries, including 26 percent in member countries of the Organization for Economic Cooperation and Development and 52 percent in the United States.

Nuclear power. Nuclear power remains a nonpolluting option in the minds of many. And, indeed in some nations — notably France, where it provides nearly 70 percent of the electricity consumed — it makes a substantial contribution. But with limited exceptions, new nuclear power plants are not being built, largely due to cost overruns, delays, and, perhaps most importantly, public fears in the wake of the Chernobyl and Three Mile Island incidents.

Prospects for nuclear power are particularly bleak in the United States, where capital costs per kilowatt of installed capacity have increased by a factor of four in real terms for plants recently completed, compared with a typical plant completed in 1971. In addition, construction times doubled while plant performance remained generally mediocre. Consequently, nuclear power has become a far less attractive option in economic terms. No orders for new nuclear reactors have been placed in the United States since 1978, and the 13 orders that were placed between 1975 and 1978 were canceled or deferred indefinitely. Few, if any, new orders are likely during the rest of this decade. Even if new orders were placed, the long time lag in construction of nuclear plants would delay significant increases in electricity production until early in the next century.

Still, new technologies — especially in Japan and Sweden — might make nuclear power an option more acceptable to the public. Japan has developed a small experimental reactor known as Joyo, or "eternal flame." Called a "breeder" reactor because it produces its own fuel, Joyo has been running for several years, and a larger version, Monju, is scheduled to begin operating soon. Officials expect the demonstration to be followed by three progressively more powerful demonstration reactors, culminating in 1,500-megawatt-scale commercial plants in the 2010 to 2030 time frame.

In Sweden, Asea Brown Boveri has developed a so-called "inherently safe" PIUS reactor, which it claims is capable of withstanding earthquakes, floods, fires, explosions, and virtually any other upset. Similarly, ABB has developed a means of immobilizing and storing waste that it says will keep the PIUS reactor safe for 10,000 years. Whether ABB's designs can actually fulfill such claims is uncertain. It is clear, however, that if widespread interest in nuclear power is revived by concerns over global warming, these technologies will hold promise.

Conclusion

Whether nuclear power is revived, coal is cleaned, or sunlight matures into a source of perpetual, clean energy, it seems unarguably evident that the world is moving in a new direction. Governments and businesses alike are being propelled by a variety of imperatives — conservation, environmental protection, consumer demand, energy efficiency, new technologies. What lies over the global horizon may be an utterly new future or merely a brighter one. What is certain, however, is that the status quo will not continue. ❑

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